PACE Ocean Ecology Sensor (OES) Requirements

ACE Science Team Meeting
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PACE Science Definition Team

- Team selected in 2011 via HQ solicitation
- Team tasked with making recommendations on science objectives, mission implementation strategies, science traceability matrices, etc.
  - 3 workshops held
- Final report submitted in Oct., 2012
  - PACE, *Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) Mission Science Definition Team Report*, 274 pp., http://decadal.gsfc.nasa.gov/PACE.html, 2012.
- Team membership
  - C. Del Castillo, chair (JHU/APL) & S. Platnik (NASA/GSFC), co-chair
  - 26 additional team members from NASA field centers, private companies, and universities.

PACE Threshold Requirements & Goals

- ***Threshold science questions*** (as defined in Section 2.2.1 and Section 2.3) encompass the required, highest-priority research that defines the PACE mission. **Threshold measurement and mission requirements** are those that are imperatives to answering the threshold science questions.
- ***Goal science questions*** (as defined in Section 2.2.2.12, Section 2.3, and Section 2.4.1) describe additional science research that the PACE mission could potentially accomplish. Goal measurement and mission requirements add value to the mission by increasing the quality and quantity of the retrieval information. **Goal measurement and mission requirements** can enable research regarding the goal science questions or permit enhanced research concerning threshold and goal science questions. Goals increase the number of data products (including atmospheric and terrestrial parameters) from the mission and enhance the value of PACE data for science and applications. However, the SDT emphasizes throughout this document that achieving goal requirements cannot compromise any of the threshold requirements.

PACE, *Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) Mission Science Definition Team Report*, 274 pp., http://decadal.gsfc.nasa.gov/PACE.html, 2012.

PACE Instrument Options

Table 1. PACE instrument options mapped to discipline-specific threshold and goal science questions.

Instrument Options	Science Questions	Brief Instrument Description
OCI	Threshold Ocean and Goal Terrestrial Ecology Science Questions: SQ-1 through SQ-7, TSQ-1 through TSQ-3 Partially addresses ASQ-1 for aerosols	Hyperspectral imager with 5nm resolution from 350-800 nm + 2 NIR bands (one of which should be centered at 865 nm) + 3 SWIR bands (1240 nm, 1640 nm, and 2130 nm). 1 km^2 spatial resolution.
OCI/OG	OCI questions (with enhanced research capabilities) + Goal Coastal Science Questions CSQ-1 through CSQ-4	OCI instrument with added atmospheric correction bands, spectral subsampling, improved global coverage, and/or enhanced performance over threshold; spatial resolution better than 500 m x 500 m
OCI+	OCI questions + Threshold Atmosphere Science Question ASQ-1	OCI instrument with 3 additional NIR and SWIR bands at 1 km^2 spatial resolution.
OCI-3M	OCI questions + Goal Atmosphere Science Questions ASQ-4 and ASQ-5	OCI instrument and a 3M imager
OCI/A	OCI+ questions + Goal Atmosphere Science Question ASQ-2	OCI+ instrument and selected atmospheric bands at 250 m x 250 m spatial resolution.
OCI/A-3M	OCI-3M and OCI/A questions + Goal Atmosphere Science Question ASQ-3	OCI/A instrument and a 3M imager

PACE Ocean Ecosystem Radiometer Threshold (minimum) Requirements

- 5 nm resolution measurements from 350 to 800 nm
  - Download of complete 5 nm resolution data
- 26 multispectral (‘aggregate’) band products (see next slide for details)
- Stability
  - 0.1% radiometric stability knowledge (mission duration)
  - 0.1% radiometric stability (1 month prelaunch verification)
- 2-day global coverage
- Sensor tilt (±20^{o}) for glint avoidance
- Polarization: < 1.0% sensor radiometric sensitivity,
  < 0.2% prelaunch characterization accuracy
- < 2% prelaunch radiance calibration accuracy (minimum)
- 1 km spatial resolution @ nadir
- No saturation in UV to NIR bands
- 5 year minimum design lifetime

PACE OES Multispectral Bands

High spectral resolution range (5 nm)

'aggregate band' list

λ	Δλ	Ltyp	Lmax	PACE OES SNR-spec (1 km)	SeaWiFS SNR	MODIS SNR
350	15	7.46	35.6	300		
360	15	7.22	37.6	1000		
385	15	6.11	38.1	1000		
412	15	7.86	60.2	1000	897	1861
425	15	6.95	58.5	1000		
443	15	7.02	66.4	1000	967	2487
460	15	6.83	72.4	1000		
475	15	6.19	72.2	1000		
490	15	5.31	68.6	1000	1010	2672
510	15	4.58	66.3	1000	1000	
532	15	3.92	65.1	1000		2155
555	15	3.39	64.3	1000	870	2271
583	15	2.81	62.4	1000		
617	15	2.19	58.2	1000		
640	10	1.90	56.4	1000		
655	15	1.67	53.5	1000		
665	10	1.60	53.6	1000	570	1839
678	10	1.45	51.9	2000 @ 4km		2070
710	15	1.19	48.9	1000		
748	10	0.93	44.7	600		1311
765	40	0.83	43.0	600	522	
820	15	0.59	39.3	600		
865	40	0.45	33.3	600	364	1285
940	25	0.78	21.0	150		
1245	20	0.088	15.8	250		51
1378	10	0.35	9.5	100		
1640	40	0.029	8.2	250		39
2130	15	0.008	2.2	15		
2250	50	0.07	2.1	150		

Units: mW/cm^2 µm str

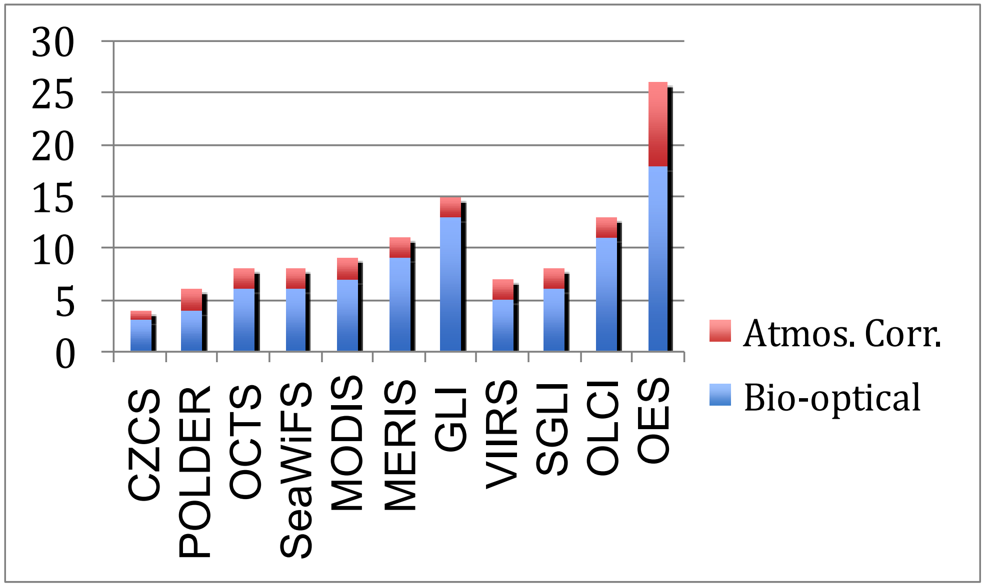
Cloud & Aerosol augmentations to Ocean band set

Ocean UV-NIR bands: Minimum SNR values based on sensitivity studies of impacts of noise-induced atmospheric correction errors and subsequent errors in 3 key geophysical products (chlorophyll-a, particulate backscattering coefficient, and colored dissolved organic matter).

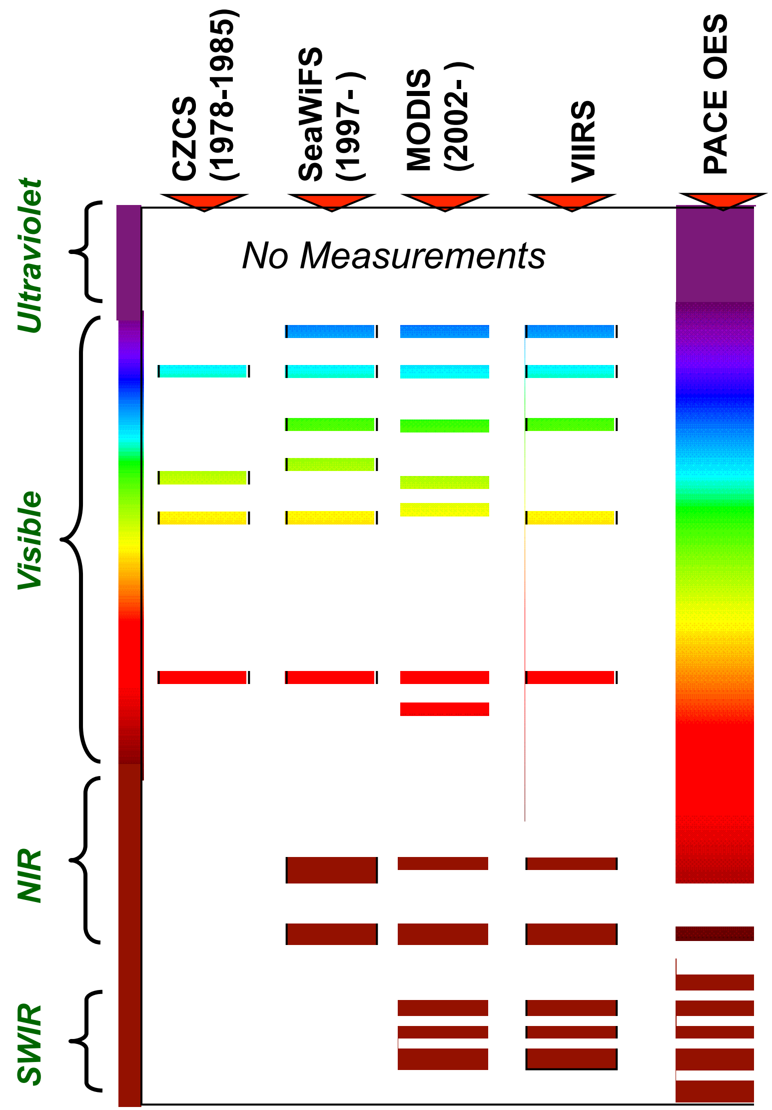
Basically, product error becomes asymptotically insensitive to noise as SNR increases. The SNR-spec values are estimates of this asymptote.

ACE 2130 nm ocean band dropped.

OES vs. Other OC Sensors



Number of OC multispectral bands



PACE Science Goals: Additional/Revised Requirements

- Oceans
  - Spatial resolution ≤ 500 m
  - Aerosol height band
  - 0.5% prelaunch calibration accuracy
  - 1-day global coverage
  - Hyperspectral data from 800-900 nm
  - 1-2 nm spectral resolution
  - NO_2 & O_3 measurement capabilities
  - 10-yr design life
  - Saturation @ 1.2xL_{max}
- Atmosphere (aerosol & cloud)
  - Spatial resolution = 250 m @ 665, 763, 865, 1640, 2135, & 2250 nm

Platform Requirements

- Orbit permitting 2-day global coverage of ocean radiometer measurements
- Sun-synchronous orbit with crossing time between 10:30 a.m. & 1:30 p.m.
- Storage and download of full spectral and spatial data
- Monthly lunar calibration at 7^o phase angle through Earth observing port

Ocean Parameters/Data Products: An Update

Current Validated Climate Data Records (CDRs)

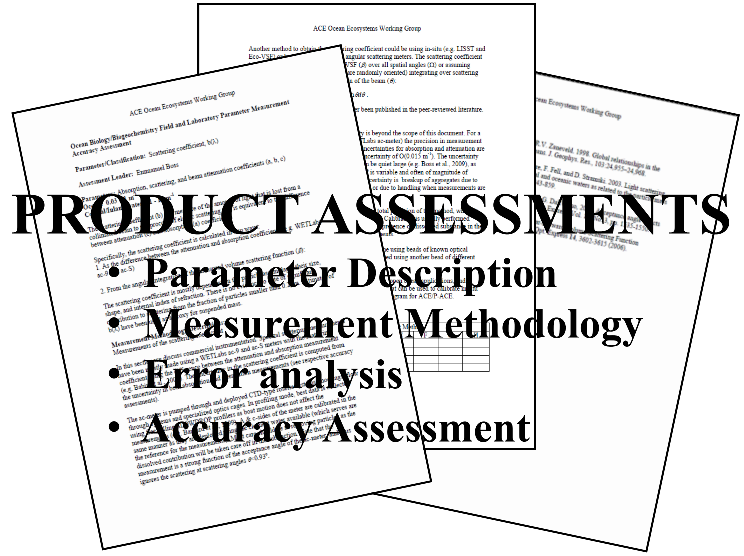
- Normalized water-leaving radiances
- Chlorophyll-a
- Diffuse attenuation coefficient (490 nm)

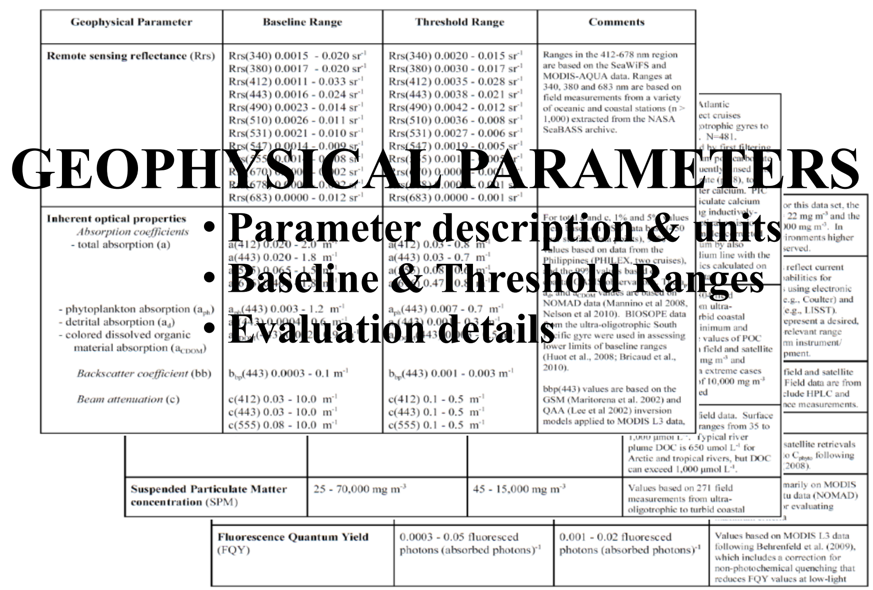
Candidate CDRs

- Inherent optical properties
- Spectral Kd
- Euphotic depth
- Spectral remote sensing reflectance
- Particulate organic carbon concentration
- Primary production
- Calcite concentration
- Colored dissolved organic matter
- Photosynthetically available radiation
- Fluorescence line height
- Total suspended matter
- Trichodesmium concentration

Research Products

- Particle size distributions & composition
- Phytoplankton carbon
- Dissolved organic matter/carbon
- Physiological properties
- Phytoplankton pigment absorption spectra
- Export production
- Functional/Taxonomic groups



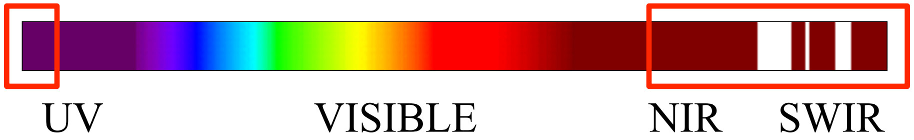


BACK-UP

ACE: Measurement Requirements

- ATMOSPHERIC CORRECTIONS
  - Spectral anchoring with UV band (~350 nm)
  - Open ocean bands in NIR [748 (10 nm bw), 765 (40 nm), 820 (15 nm), 865 (40 nm)]
  - Turbid water SWIR [1245 (20 nm), 1640 (40 nm), 2135 (50 nm)]

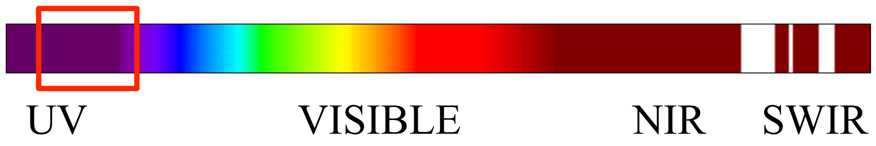
  - This is one of the important areas of overlap between PACE aerosol and ocean science communities



ACE : Measurement Requirements

Aerosol, Cloud, & Ocean Ecosystem Mission

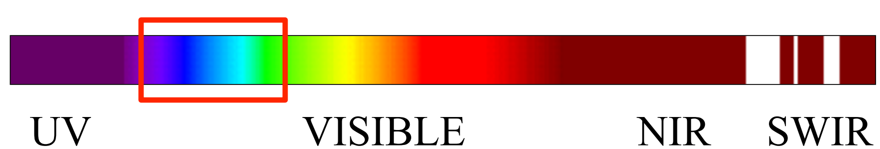
- ATMOSPHERIC CORRECTIONS
- CDOM / SEPARATION FROM PIGMENT ABSORPTION
  - Current uncertainty impacts NPP assessment by 16 Gt y^{-1} (total ~50 Gt y^{-1})
  - Near UV bands [360 (15 nm),380 (15 nm)]



ACE : Measurement Requirements

Aerosol, Cloud, & Ocean Ecosystem Mission

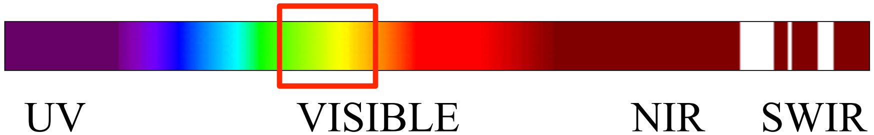
- ATMOSPHERIC CORRECTIONS
- CDOM-PIGMENT SEPARATION
- PHYTOPLANKTON ABSORPTION SPECTRA
    - Productivity keyed to total pigment absorption, not simply chlorophyll concentration
    - Assess both the amplitude and breadth of absorption spectra
    - 15 nm resolution in blue-green region



ACE : Measurement Requirements

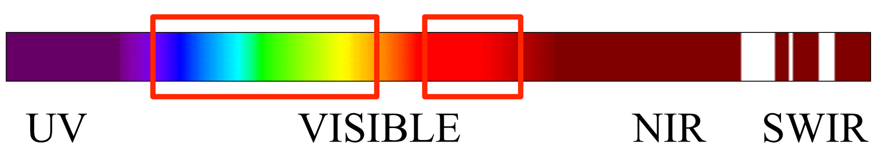
Aerosol, Cloud, & Ocean Ecosystem Mission

- ATMOSPHERIC CORRECTIONS
- CDOM-PIGMENT SEPARATION
- PHYTOPLANKTON ABSORPTION SPECTRA
- PHYTOPLANKTON CARBON; TOTAL PARTICULATE CARBON
    - Chlorophyll is not biomass
    - Flow of carbon through the total particulate carbon pool
    - Carbon stocks related to particulate scattering coefficients ***and*** spectral slope
    - 15 nm bands in the region of minimum pigment absorption



ACE : Measurement Requirements

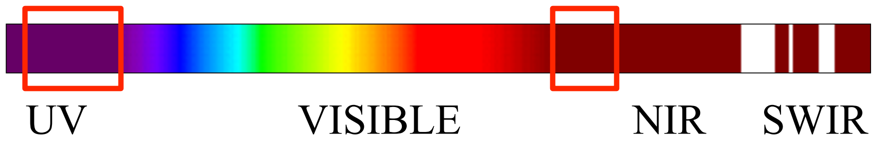
- ATMOSPHERIC CORRECTIONS
- CDOM-PIGMENT SEPARATION
- PHYTOPLANKTON ABSORPTION SPECTRA
- PHYTOPLANKTON/TOTAL PARTICULATE CARBON
- PHYTOPLANKTON PHYSIOLOGY
  - How do we interpret observed chlorophyll trends from heritage sensors? Biomass or physiology? Relationship to productivity?
  - How do we account for unique nutrient effects? How is environmental change linked to distributions of specific limiting nutrients?
  - What are the ecological responses to atmospheric nutrient deposition?
  - Ratio of pigment absorption to phytoplankton carbon - general light and nutrient effects
  - Chlorophyll fluorescence quantum yield [665 (10 nm), 678 (10 nm), 710 (15 nm)] – detection of iron-stressed populations



ACE : Measurement Requirements

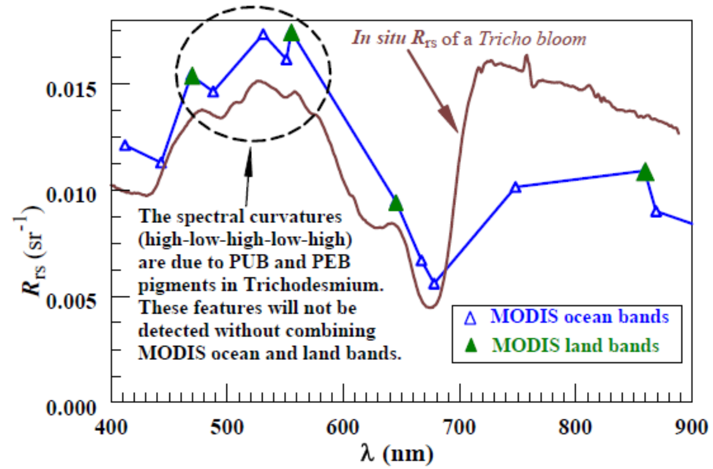
Aerosol, Cloud, & Ocean Ecosystem Mission

- ATMOSPHERIC CORRECTIONS
- CDOM-PIGMENT SEPARATION
- PHYTOPLANKTON ABSORPTION SPECTRA
- PHYTOPLANKTON/TOTAL PARTICULATE CARBON
- PHYTOPLANKTON PHYSIOLOGY
- EUTROPHIC WATERS / HARMFUL ALGAL SPECIES
    - How are bloom events changing? Duration, extent, timing, composition?
    - ‘Red-edge’ algorithms for pigment stocks (red-NIR band differences)
    - Near-UV and/or 710 nm band for HABs



ACE : Measurement Requirements

Aerosol, Cloud, & Ocean Ecosystem Mission



- ATMOSPHERIC CORRECTIONS
- CDOM-PIGMENT SEPARATION
- PHYTOPLANKTON ABSORPTION SPECTRA
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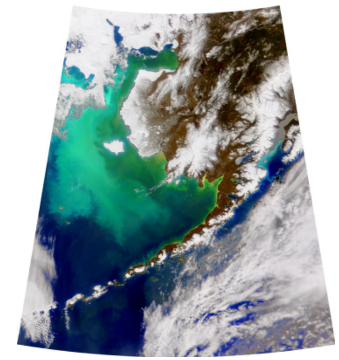
- PHYTOPLANKTON PHYSIOLOGY
- EUTROPHIC WATERS / HARMFUL ALGAL SPECIES
- PHYTOPLANKTON FUNCTIONAL GROUPS
    - A change in the composition of the phytoplankton community can be as/more important than a change in the bulk standing stock – ecologically and biogeochemically
    - ‘Multi-band’ approaches for targeted organism
    - ‘Hyperspectral’ (5 nm) derivative analysis for multiple broad groups

ACE : Measurement Requirements

Aerosol, Cloud, & Ocean Ecosystem Mission



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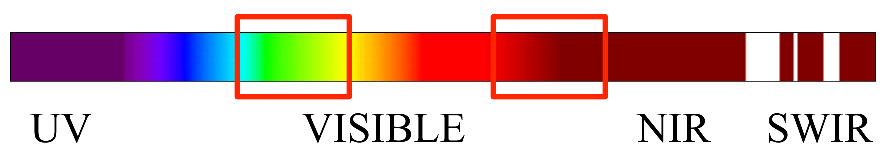
- PHYTOPLANKTON PHYSIOLOGY
- EUTROPHIC WATERS / HARMFUL ALGAL SPECIES
- PHYTOPLANKTON FUNCTIONAL GROUPS
- PARTICULATE INORGANIC CARBON
    - Calcifying organisms play a key role in carbon export and surface carbon chemistry
    - Green, Red, NIR bands for open ocean and coastal waters



ACE : Measurement Requirements

Aerosol, Cloud, & Ocean Ecosystem Mission

- ATMOSPHERIC CORRECTIONS
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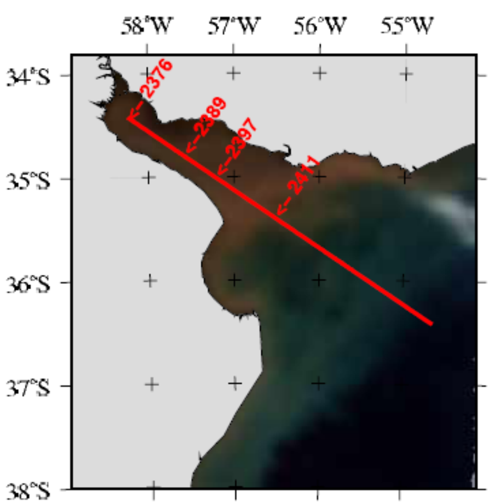
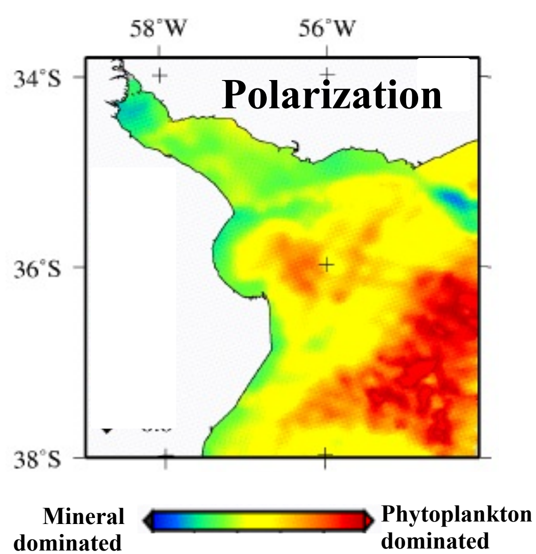
- PHYTOPLANKTON PHYSIOLOGY
- EUTROPHIC WATERS / HARMFUL ALGAL SPECIES
- PHYTOPLANKTON FUNCTIONAL GROUPS
- PARTICULATE INORGANIC CARBON
- LAND-OCEAN MATERIAL EXCHANGE
    - Distinguishing mineral and biotic particles through polarization properties



Rio de la Plata



ACE : Measurement Requirements

Aerosol, Cloud, & Ocean Ecosystem Mission

- ATMOSPHERIC CORRECTIONS
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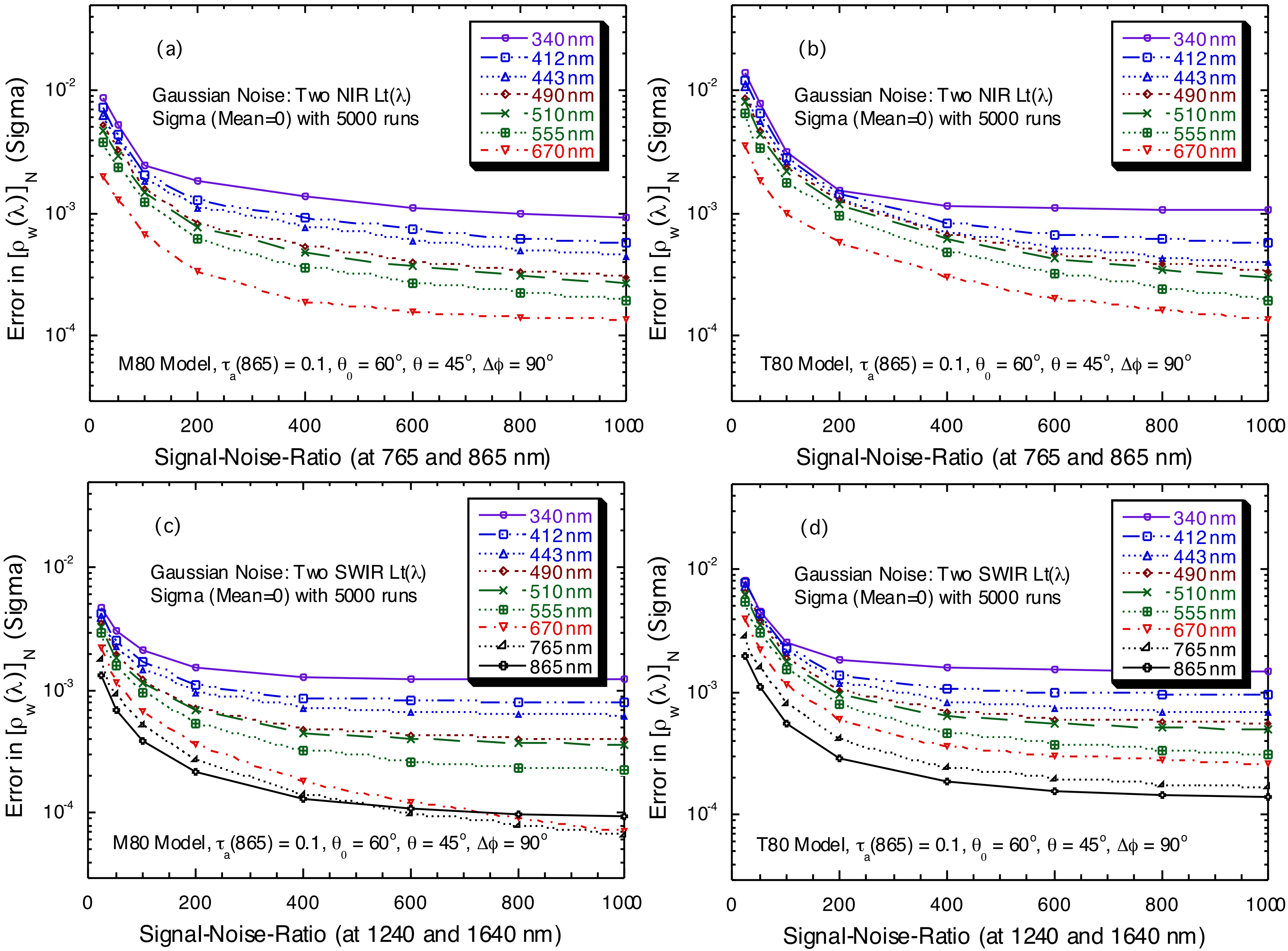
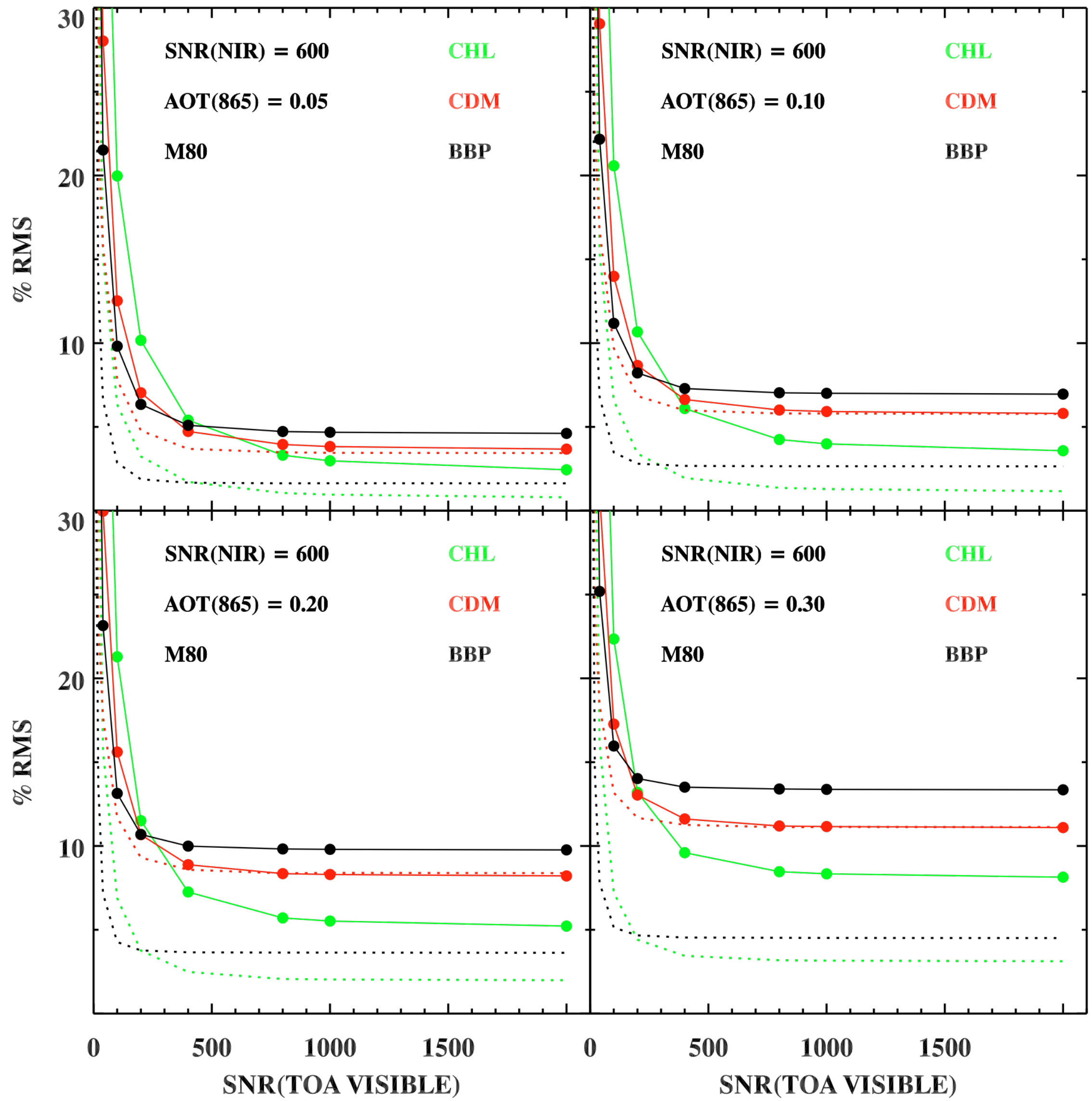
- PHYTOPLANKTON/TOTAL PARTICULATE CARBON
- PHYTOPLANKTON PHYSIOLOGY
- EUTROPHIC WATERS / HARMFUL ALGAL SPECIES
- PHYTOPLANKTON FUNCTIONAL GROUPS
- PARTICULATE INORGANIC CARBON
- LAND-OCEAN MATERIAL EXCHANGE
- HERITAGE OCEAN COLOR BANDS
  - 412, 443, 490, 510, 532, 555, 665, 678, 710, 765, 865 nm


(a)
Gaussian Noise: Two NIR Lt(λ)
Sigma (Mean=0) with 5000 runs
340 nm
412 nm
443 nm
490 nm
510 nm
555 nm
670 nm
M80 Model, τa(865) = 0.1, θ0 = 60°, θ = 45°, Δφ = 90°
Error in [ρw(λ)]N (Sigma)
Signal-Noise-Ratio (at 765 and 865 nm)
(b)
Gaussian Noise: Two NIR Lt(λ)
Sigma (Mean=0) with 5000 runs
T80 Model, τa(865) = 0.1, θ0 = 60°, θ = 45°, Δφ = 90°
Error in [ρw(λ)]N (Sigma)
Signal-Noise-Ratio (at 765 and 865 nm)
(c)
Gaussian Noise: Two SWIR Lt(λ)
Sigma (Mean=0) with 5000 runs
765 nm
865 nm
M80 Model, τa(865) = 0.1, θ0 = 60°, θ = 45°, Δφ = 90°
Error in [ρw(λ)]N (Sigma)
Signal-Noise-Ratio (at 1240 and 1640 nm)
(d)
Gaussian Noise: Two SWIR Lt(λ)
Sigma (Mean=0) with 5000 runs
T80 Model, τa(865) = 0.1, θ0 = 60°, θ = 45°, Δφ = 90°
Error in [ρw(λ)]N (Sigma)
Signal-Noise-Ratio (at 1240 and 1640 nm)



Average ocean retrieval AOT ~ 0.1, so an SNR ~ 1000 in the visible is an adequate minimum requirement. Fluorescence bands need a higher SNR.

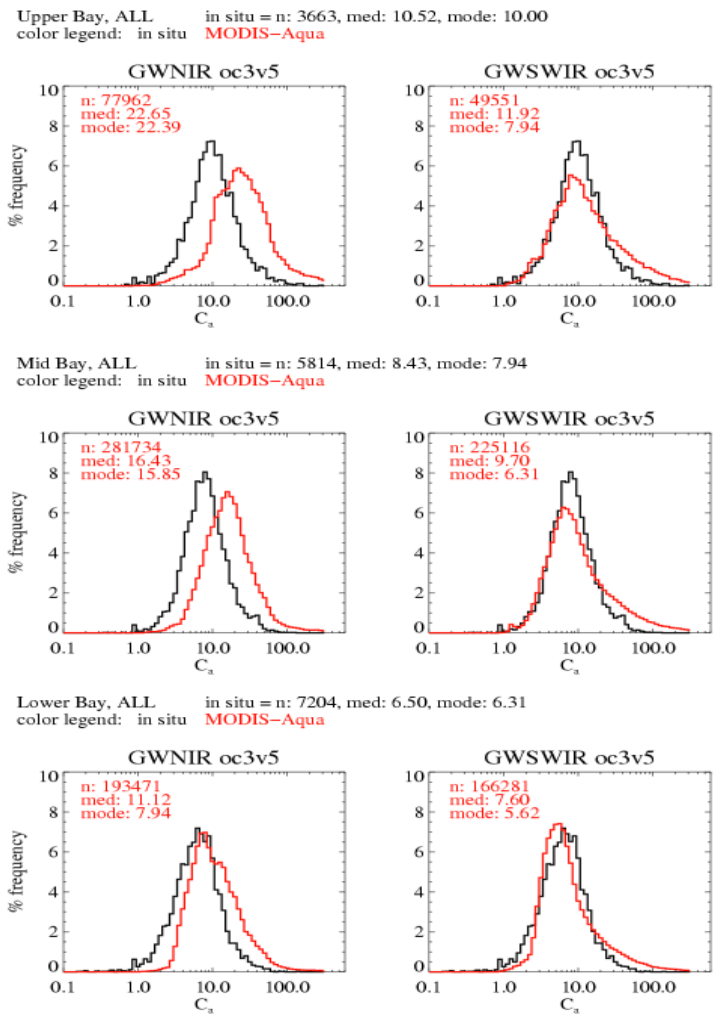
SWIR-based Corrections: Impact on Chlorophyll Retrievals

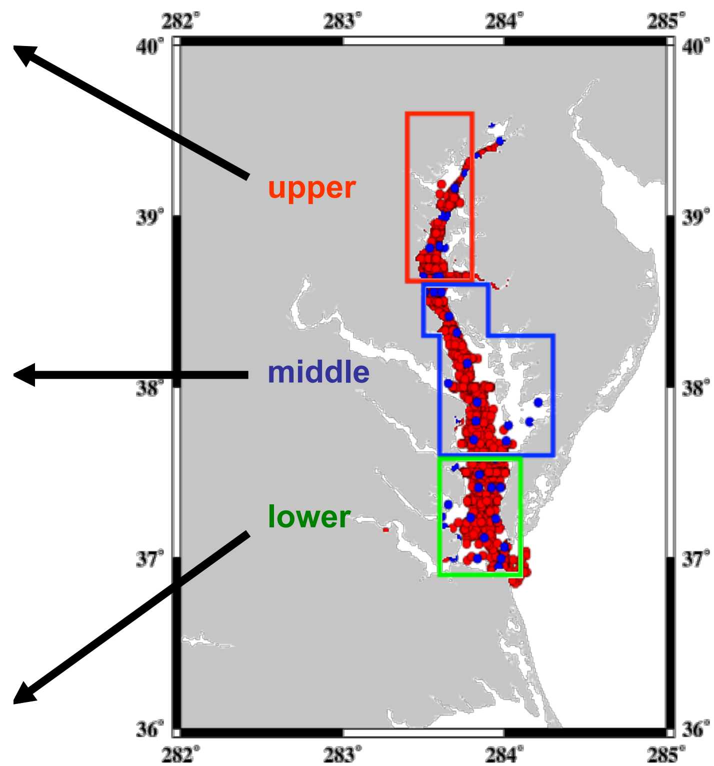
Chlorophyll (mode)

Field: 10 mg/m^3
w/o SWIR: 22 mg/m^3
w/ SWIR: 8 mg/m^3

Field: 8 mg/m^3
w/o SWIR: 16 mg/m^3
w/ SWIR: 6 mg/m^3

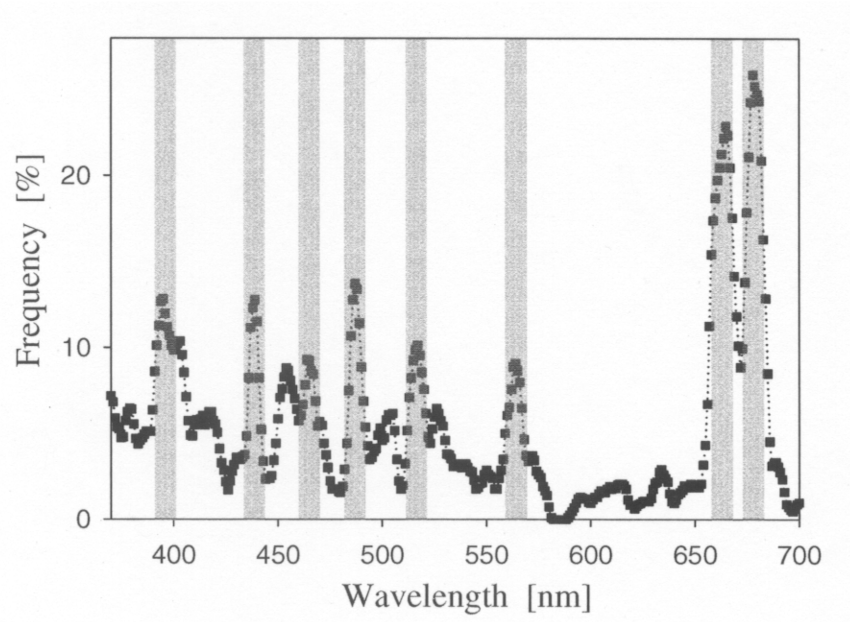
Field: 6 mg/m^3
w/o SWIR: 8 mg/m^3
w/ SWIR: 6 mg/m^3



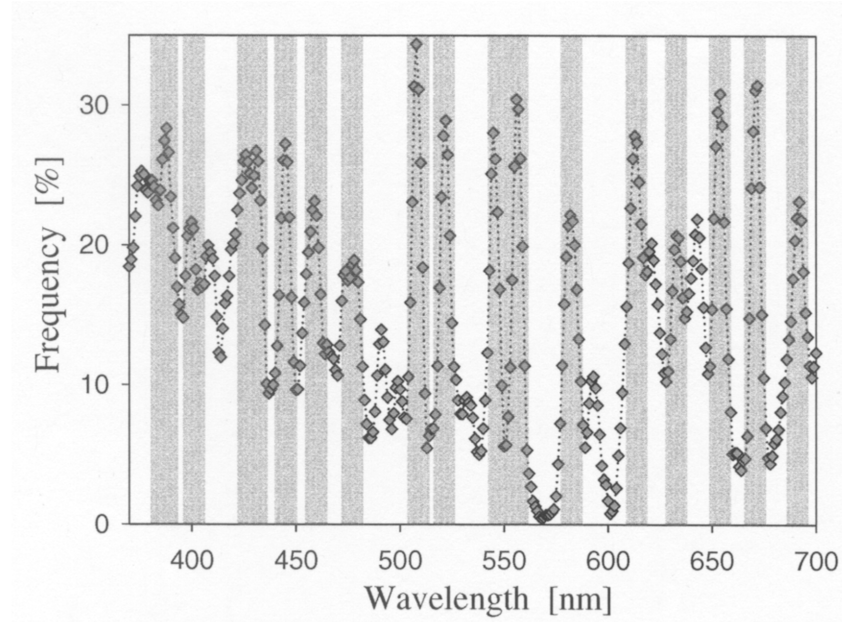


Chesapeake Bay

Phytoplankton Functional Groups: Spectral Derivative Analyses



Spectral distribution of the frequency where the 1st-order derivative of ocean reflectance = 0.



Spectral distribution of the frequency where the 2nd-order derivative of ocean reflectance = 0.

Lee, Z-P., K. Carder, R. Arnone, & M-X. He, Determination of primary spectral bands for remote sensing of aquatic environments, *sensors*, 7, 3428-3441, 2007.

On-Orbit Sensor Stability Traceability